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THE DEPENDENCE OF DYNAMIC STRENGTH

OF CYLINDRICAL PRESSURE VESSELS

ON GEOMETRICAL PARAMETERS

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Table of Contents

	<u>Page No.</u>
Introduction	1
Definition of Problem	1
Experiments	1
Analysis	1 - 2
Results	2 - 3
Conclusions	3
Necessary Future Work	3 - 4
Acknowledgment	4
FIGURES	
Figure 1	5
Figure 2	6
Figure 3	7
Distribution List	8 - 9 - 10

THE DEPENDENCE OF DYNAMIC STRENGTH OF CYLINDRICAL PRESSURE VESSELS ON GEOMETRICAL PARAMETERS

Introduction:

Interest in techniques for dynamic pressure vessel design has increased in the recent past as a result of the much wider demand for these devices. A large area of application is connected with nuclear reactor design. Another important related application involves the design of containers for placing unstable or chemically reactive materials in the neighborhood of an accelerator or in a nuclear reactor. The latter was the motivation for the current work. Of course, the application for dynamic pressure vessels is rather wide-spread and has extensive use in chemical engineering.

Definition of Problem:

The problem was to develop sufficient data to permit dynamic pressure vessel design to be done on a quantitative basis. Stating the problem more specifically, how can a mass "m" of detonating explosive be completely contained in a pressure vessel; what vessel diameter "d" and wall thickness "t" are required and, finally, how do these depend on the strength of the material? The more difficult problem of doing a theoretical analysis of the dynamic behavior of cylinders under explosive loading conditions was not considered.

Experiments:

Experimental information was obtained by detonating spheres of C4 explosive* centrally located in cylindrical containers. Slightly different results would be expected for other explosives. End capping was accomplished by placing the pipe in a vertical position, standing on a steel plate. Another thick steel plate was placed over the open top end of the cylinder and the assembly was loaded down with about 500 lbs. of lead. With this system, explosive spheres of different masses were detonated inside the cylinders to determine the maximum amount of explosive that could be contained, without rupture, inside various cylinders. Only one shot was fired in each cylinder. The techniques of end capping in this experiment is not critical if the cylinders have a length of 5 or 6 times the inside diameter. The side wall of the cylinder receives the first impulse before the end plates experience any disturbance. Certainly one would expect oscillations in the gaseous detonation products which would supply additional impulses to the side wall. However, these seem to be negligible consequence because of expansion of the products down the length of the pipe. High speed photographs have been taken of an expanding aluminum pipe loaded with 12 gms of explosive. The outside diameter was 3 inches and the wall thickness $\frac{1}{4}$ inch. The expansion took place in about 50 μ sec.

Analysis:

The first set of data was obtained for extruded aluminum 6061T6 tubing.
*C4 explosive was used because a given mass could easily be rolled into a sphere.

Log-Log plots of mass "m" of explosive (i.e., explosive limit) against inside diameter "d" for constant wall thickness give linear plots for constant wall thickness "t". Figure 1 shows a family of such curves all with the same slope, for various wall thicknesses. These curves are convenient for vessel design in that m, t and d can be read directly from the curves. The equations for these curves is of the form

$$\log m = a + b \log d \quad (1)$$

where only the intercept a is dependent on t. If a vs t is plotted on semilog paper, the data can be approximated with a straight line relationship; i.e., we have the form

$$a = k \log t + \log c \quad (2)$$

where log c is the y intercept.

Or

$$a = \log ct^k \quad (3)$$

Putting this in equation 1 gives

$$m = ct^k d^b$$

Evaluating* the constants from the aluminum 6061T6 data

$$m = 15.5 t^{4/3} d^{1.78} \quad (4)$$

where m is in grams, t and d are in inches

As Figure 2 shows, a log-log plot of $m/t^{4/3}$ as a function of d gives a linear plot. Although this curve is not the most convenient one for chamber design, it demonstrates the agreement between the equation and the experimental data.

Results:

Some other aluminum alloys were tested and were selected on the basis of availability. Alloy 2024T4 does not differ significantly from 6061T6. Alloy 5058 may be slightly better, whereas 5456 may be significantly better. The aluminum 7075 does not seem quite as good as 6061T6. Stainless steel tubing 304 was tested. However, in the larger diameters, the weld failed instead of the material itself. Figure 3 shows the 6061T6 curve with points for other materials plotted for comparison.

Where insufficient data exists for a particular material, it is reasonable to draw the best straight line through the points which are parallel to the 6061 curve. If the curves did not have the same slope they would intersect and a material stronger than 6061T6 in one region would appear to be weaker in the region on the other side of the intersection.

* All equations were obtained from least squares calculations

Therefore, if plots of the form shown in Figures 2 and 3 are made for different strength materials, a family of parallel curves should result. The vertical intercept would be a function of the dynamic strength of the material. It is well known that the difference between static and dynamic response of materials differs considerably from one material to another. Consequently, no correlation can exist between statically measured engineering strength and parameters and the position of the explosive limit curve.

In the application of the data Figure 1 can be used. For a given m , suitable combinations of t and d can be examined in terms of available space and radiation absorption in the walls, if applicable. Tolerances on commercial tubing are very loose and some safety factor must be introduced. A common, conservative safety factor is 2. Aluminum 6061T6 will undergo approximately 10% increase in diameter before rupture. However, at half the explosive limit expansion is less than 2%.

Experience indicates that the most difficult problem is preventing side wall rupture. If the cylindrical chamber is long enough, end-capping is not difficult. Difficulties start to arise when the ratio of inside length to inside diameter falls below about 6. In some cases long threaded plugs were successfully used for end caps. In others, flanges were welded on the ends and closing plates were bolted to these. In all cases, the newly-designed vessels should always be test-fired. It should also be pointed out that the above data were obtained from firings at one atmosphere. When the vessel is evacuated the explosive limit is reduced very roughly 10%.

In some environments a shock wave from the vessel may be troublesome. This can be remedied by using a shock absorbing material. In extreme situations, another container can be built around the vessel with sufficient clearance to prevent the expanding inner container from closing the gap. The space between the concentric containers is then evacuated.

Complete container design can be accomplished rather routinely using aluminum 6061T6 or 2024T4. Vessels from other alloys, 304 stainless steel, aluminum 5058H32, 5456H323 and 7075T6 can be designed with less precision. Where other materials are of interest, design information can be generated by measuring the explosive limit of two pipes of different dimensions. Thus, a curve similar to that in Figure 3 can be roughed in.

Conclusions:

Future work which is needed involves obtaining curves for materials whose strengths are different from that of 6061T6. Lead may not have much practical application but would introduce a large change in material strength for studies of strength dependence.

Necessary Future Work:

A one-shot strength test is also needed. A simple test could consist of firing a solid cone of explosive inside a pipe of fixed dimensions. Where

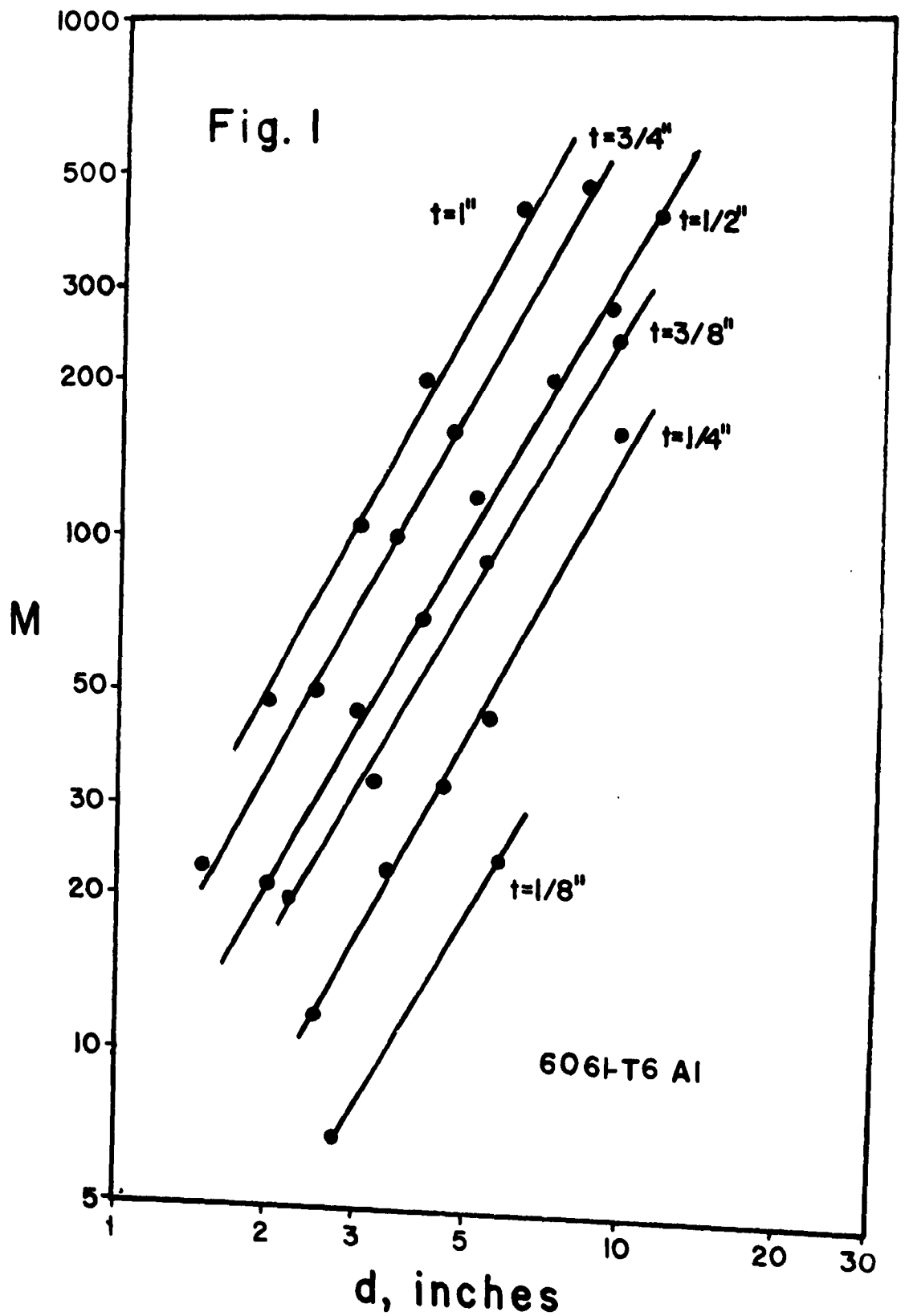
the clearance between the wall and the explosive is smallest, the chance of rupture is greatest. However, once rupture starts it may propagate into regions where it might not otherwise have occurred. To prevent this, a series of saw cuts normal to the long axis are made about half way through the tube. In order to guarantee that rupture occurs in the saw cut side, the explosive cone axis is placed parallel to the cylinder axis but closer to the sawed wall. The test is arranged so that the segment of the wall closest to the explosive will rupture and where this radial clearance is a maximum no rupture occurs. Then the radial clearance (between cylinder wall and explosive cone) for the last segment that did not rupture is a measure of the strength of the material. This clearance can be correlated with the position of the design curve in Figure 2 for any new material. Thus one shot design data may be possible.

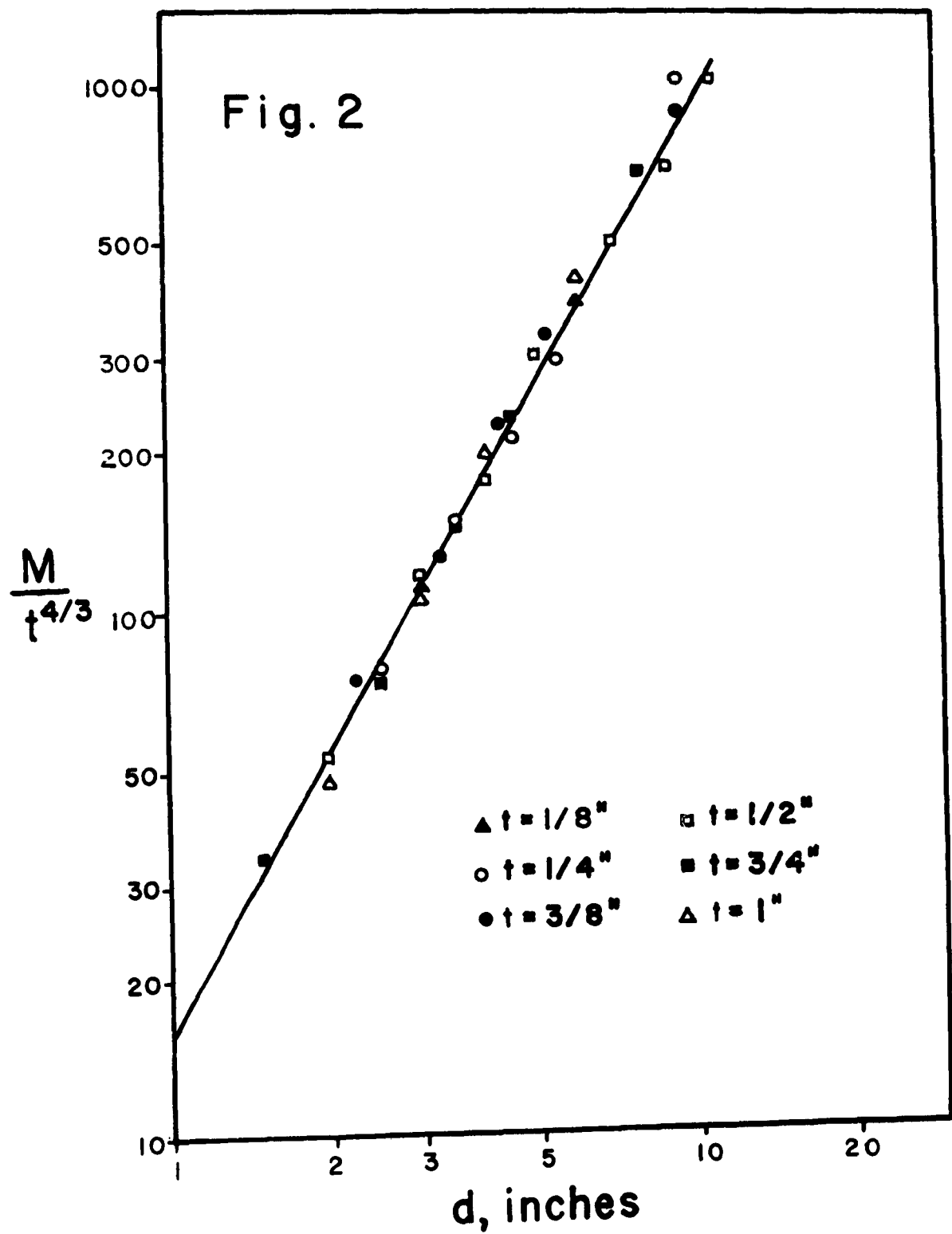
The data presented here, now makes it possible to design small cylindrical pressure vessels. Nevertheless, F. A. Loving of the DuPont Company described some "walk-in" chamber design experiments in a Company report RE-59-29 A Spherical Sound Muffling Barricade Aug 6, 1959. These experiments, however, are with spheres about 12 feet in diameter. The data cannot be applied to small cylinders.

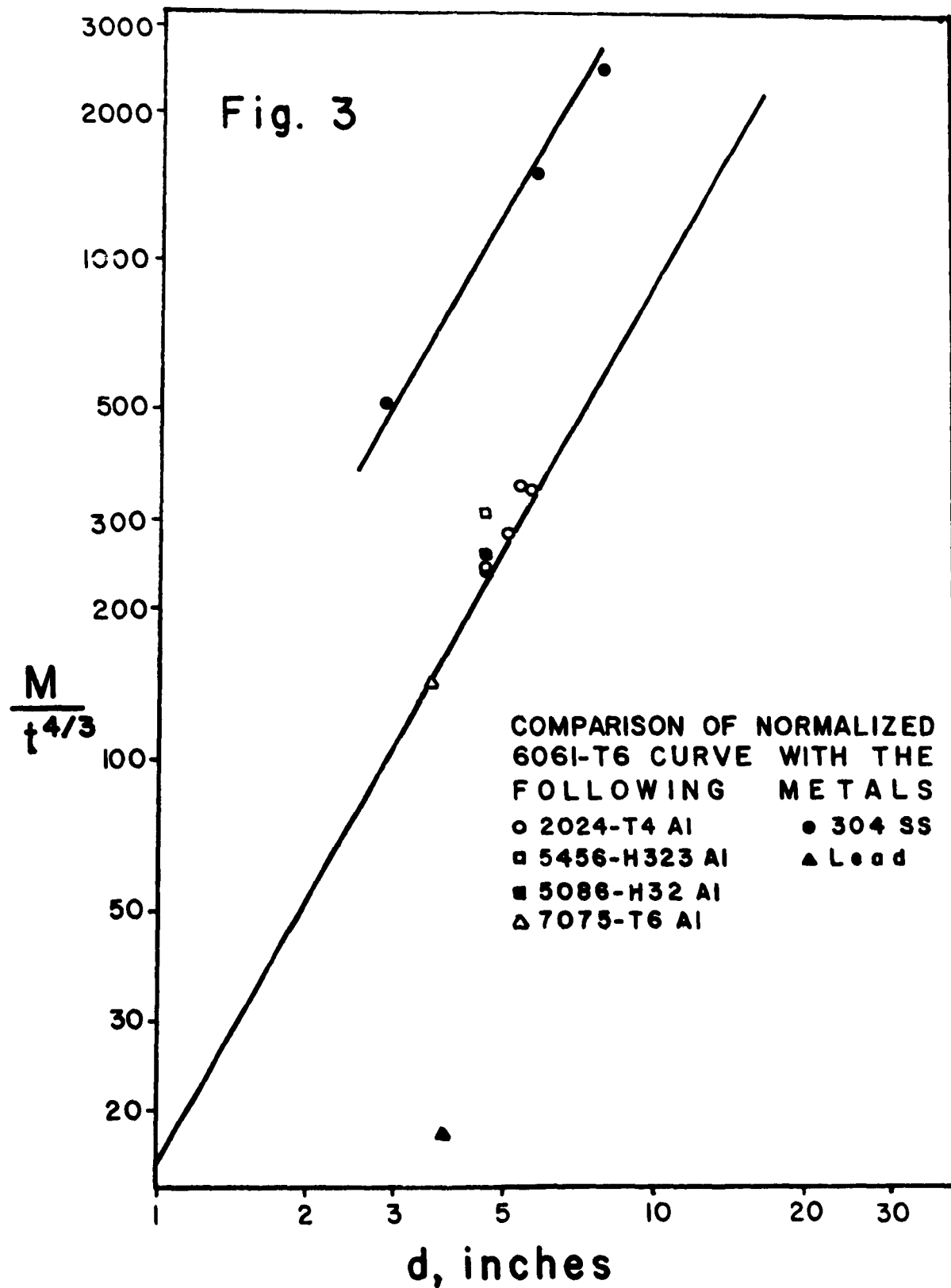
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38